

EUROSENSORS 2014, the XXVIII edition of the conference series

A Method of Fabricating Vacuum Packages with Vertical Feedthroughs in a Wafer Level Anodic Bonding Process

Mustafa Mert Torunbalci^{a,*}, Said Emre Alper^a, Tayfun Akin^{a,b}

^a*MEMS Research and Applications Center, Middle East Technical University, Ankara, TURKEY*

^b*Dept. of Electrical and Electronics Eng., Middle East Technical University, Ankara, TURKEY*

Abstract

This paper presents a new method for wafer level vacuum packaging of MEMS devices using anodic bonding together with vertical feedthroughs formed on an SOI cap wafer, eliminating the need for any sealing material or any complex via-refill or trench-refill vertical feedthrough steps. The packaging yield is experimentally verified to be above 95%, and the cavity pressure is characterized to be as low as 1 mTorr with the help of a thin-film getter. The shear strength of several packages is measured to be above 15MPa.

© 2014 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/3.0/>).

Peer-review under responsibility of the scientific committee of Eurosensors 2014

Keywords: Wafer level packaging, Vertical feedthroughs, Anodic bonding

1. Introduction

Packaging is a major interrupting block for the commercial success of MEMS devices. There are already well established wafer level hermetic packaging methods for MEMS, where the glass frit [1] and metal-based [2, 3] bonding techniques are used. However, these techniques require an intermediate bonding material, increasing not only the fabrication process steps in some approaches but also the bonding temperature and packaging stress in other approaches. The use of any intermediate material can be eliminated with the anodic bonding technique [4], which also provides a simple, relatively low temperature (possible down to 250°C), and uniform hermetic bonding between

* Corresponding author. Tel.: +90-312-210-6336; fax: +90-312-210-2304.

E-mail address: mtorunbalci@mems.metu.edu.tr

glass and silicon wafers. However, this technique is not compatible with lateral feedthroughs not only for the unwanted step heights but also due to the lack of electrical isolation between such feedthrough lines. Sealing with anodic bonding technique requires vertical feedthroughs, but such vertical structures typically require complex via-refill or trench-refill steps. This paper presents a new wafer level vacuum packaging method using anodic bonding eliminating the need for any sealing material, together with a new vertical feedthrough approach recently reported by our group [5, 6] that does not need any complex via-refill or trench-refill steps.

2. Package Design and Fabrication

Figure 1 shows a three-dimensional (3-D) view of the proposed packaging method. Vertical feedthroughs and the sealing walls are made from highly doped silicon and formed simultaneously by etching the device layer of an SOI cap wafer while the via openings are formed by etching the handle silicon layer. The exposed faces of the vertical feedthroughs can be accessed externally by wire bonds, eliminating any need for via-refill as in [7]. Figure 2 shows the major process steps of the SOI cap and the sensor wafer. The most critical step in the fabrication is the SOI to glass anodic bonding which is believed to be a complicated process since the buried oxide isolates the handle and silicon layers of the SOI cap wafer. Different solutions have been proposed for the SOI-glass anodic bonding in the literature [8, 9]. In this work, the handle and device silicon layers of the SOI cap wafer are electrically shorted with an Al layer prior to the anodic bonding. The SOI cap wafer is then bonded to a sensor wafer [10] by applying 600V at about 350°C, simultaneously forming the hermetic seal and signal transfer leads.

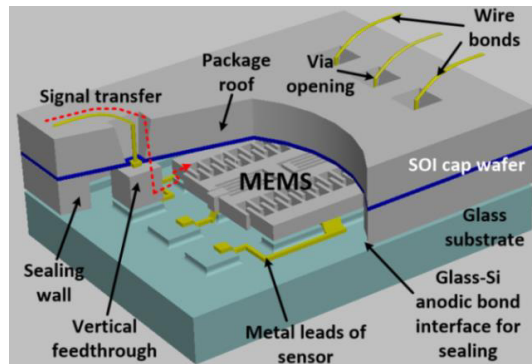


Fig. 1. 3-D view of the proposed package method.

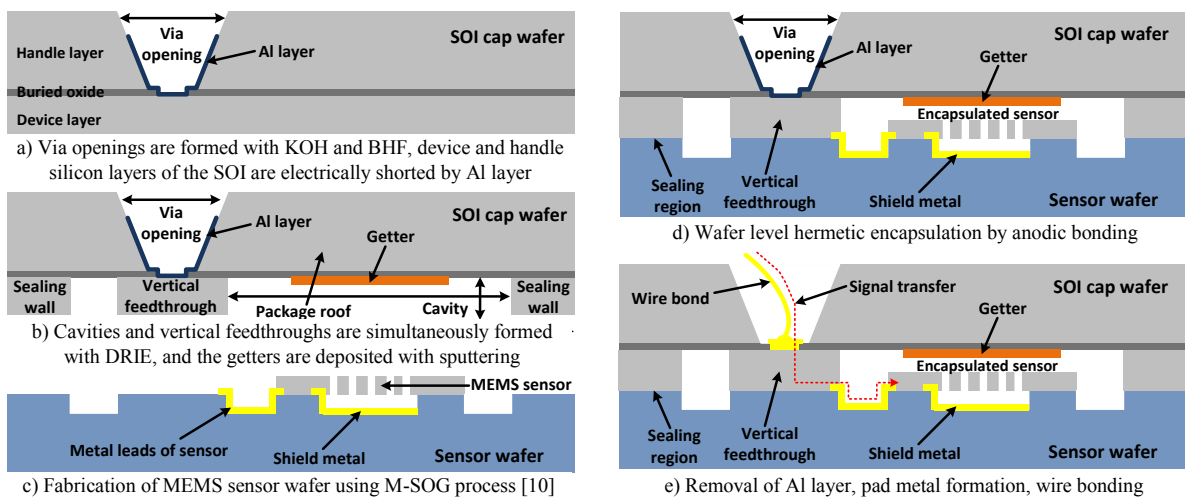


Fig. 2. Major process steps of the SOI cap and the sensor wafer.

3. Results

Figures 3 and 4 show the pictures of the packaged MEMS dies, providing the details of the via openings, sealing wall, and vertical feedthroughs. While the pitch-size of the via openings is selected to be $800\mu\text{m}$ for the first prototypes, it can be reduced to $250\mu\text{m}$ simply by reducing the handle layer thickness of the SOI cap wafer.

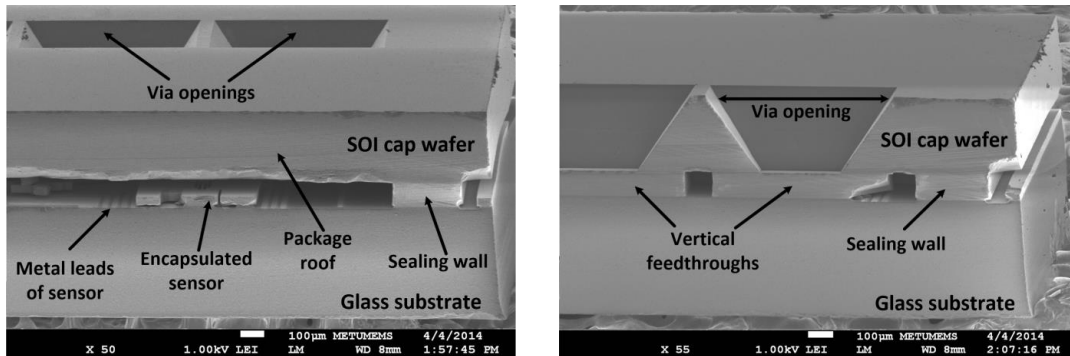


Fig. 3. SEM pictures of MEMS dies using the proposed method.

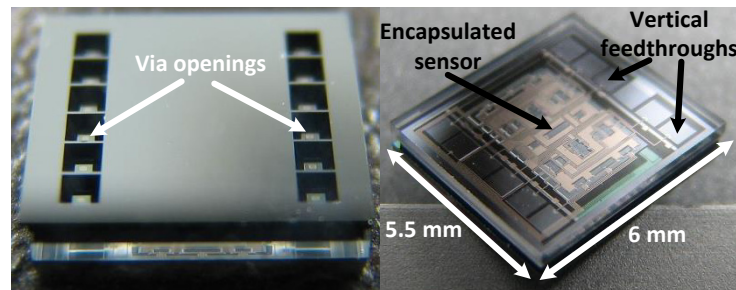


Fig. 4. Photographs of MEMS dies from the top and bottom faces, fabricated using the proposed method.

Figure 5(a) demonstrates the quality factor versus pressure characteristics of a MEMS resonator before the packaging process performed in a controlled vacuum environment, and Figure 5(b) presents the resonance characteristics of the same MEMS resonator after wafer level packaging, showing a measured quality factor corresponding to a cavity pressure of almost 1 mTorr according to the results in Figure 5(a). Resonance tests are performed on randomly selected 20 sensors on a packaged wafer, and 19 of them (95%) are verified to be packaged successfully with characteristics similar to Figure 5(b).

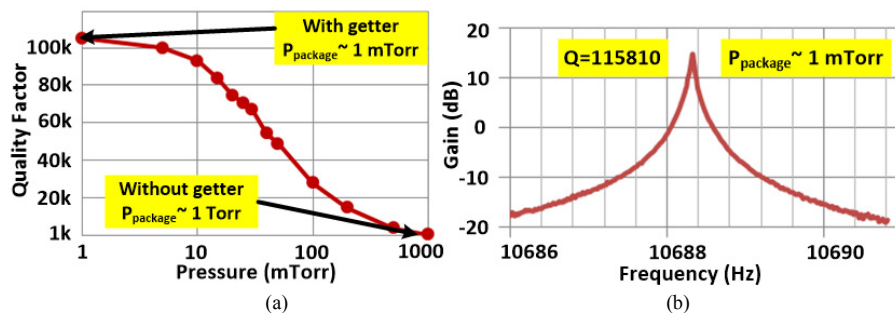


Fig. 5. Test results of the fabricated prototypes: (a) Quality factor versus pressure characteristics of a MEMS resonator obtained before packaging in a controlled vacuum environment. (b) Resonance characteristics of the same MEMS resonator after wafer level packaging, showing a measured quality factor of 115,810 corresponding to a cavity pressure of 1 mTorr according to the results in (a).

The strength of the packages fabricated using the proposed method is checked with the shear tests. Figure 6 shows the photographs of cap and sensor chips separated from each other during the shear test. The silicon-glass bonding interface is observed to withstand the shear test, as either the silicon cap or the glass substrate is broken, but not the bonding interface. This verifies that the bonding strength of the proposed method is above 15MPa, indicating a high strength sealing.

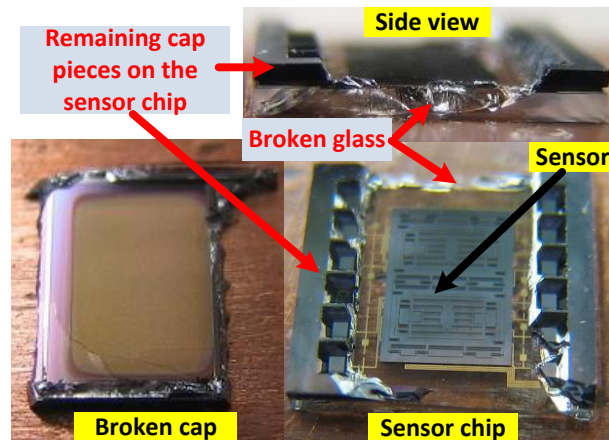


Fig. 6. Photographs of cap and sensor chips separated from each other during shear test. The silicon-glass bonding interface is observed to withstand the shear test, as either the silicon cap or the glass substrate is broken, but not the bonding interface. This verifies that the bonding strength of the proposed method is above 15MPa.

4. Conclusions

In conclusion, the new and simple method developed for wafer level vacuum packaging of MEMS devices is successfully verified to be operational, with a packaging yield over 95%, cavity pressures as low as 1 mTorr with the successfully activated thin film getters, and shear strength above 15 MPa.

Acknowledgements

This research is conducted under Industrial MEMS Project funded by State Planning Organization (currently Ministry of Development). The authors also would like to thank to Eyup Can Demir and Inci Donmez for the shear tests of the packages, and Hasan Dogan Gavcar for his helps during the fabrication.

References

- [1] G. Wu, D. Xu, B. Xiong, Y. Wang, Y. Wang, and Y. Ma, "Wafer level vacuum packaging for MEMS resonators using glass frit bonding," *J. Microelectromech. Sys.*, 21 (2012), 1484-1491.
- [2] J. S. Mitchell and K. Najafi, "A detailed study of yield and reliability for vacuum packages fabricated in a wafer level Au-Si eutectic bonding process," *Transducers* (2009), 841-844.
- [3] W. C. Welch and K. Najafi, "Au-In transient liquid phase wafer bonding for MEMS vacuum packaging," *IEEE MEMS* (2012), 807-809.
- [4] K. B. Albaugh, "Electrode phenomena during anodic bonding of silicon to borosilicate glass," *J. of Elec. Soc.*, 138 (1991), 3089-3094.
- [5] M. M. Torunbalci, S. E. Alper, and T. Akin, "Wafer level hermetic encapsulation of MEMS inertial sensors using SOI cap wafers with vertical feedthroughs," *IEEE Int. symposium on inertial sensors and systems* (2014), 1-2.
- [6] S. E. Alper, M. M. Torunbalci, and T. Akin, "Method of wafer level hermetic packaging with vertical feedthroughs," *PCT/TR2013/000298*.
- [7] A. C. Fischer, J. G. Korvink, N. Roxhed, G. Stemme, U. Wallrabe, and F. Niklaus, "Unconventional applications of wire bonding create opportunities for microsystem integration," *J. Micromech. Microeng.*, 23 (2013), 1-18.
- [8] Z. Li, Y. Hao, D. Zhang, T. Li, and G. Wu, "An SOI-MEMS technology using substrate layer and bonded glass as wafer-level package," *Sensors and Actuators A* 96 (2002), 34-42.
- [9] E. Tatar, M. M. Torunbalci, S. E. Alper, and T. Akin, "A method and electrical model for the anodic bonding of SOI and glass wafers," *IEEE MEMS* (2012), 68-71.
- [10] M. M. Torunbalci, E. Tatar, S. E. Alper, and T. Akin, "Comparison of two alternative silicon-on-glass microfabrication processes for MEMS inertial sensors," *Eurosensors* (2011), 900-903.